TECHNICAL REPORT # 18

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Date: April 1980

Subject: An Off-Set Fed Parabolic Reflector Antenna for 1296 mc/s.

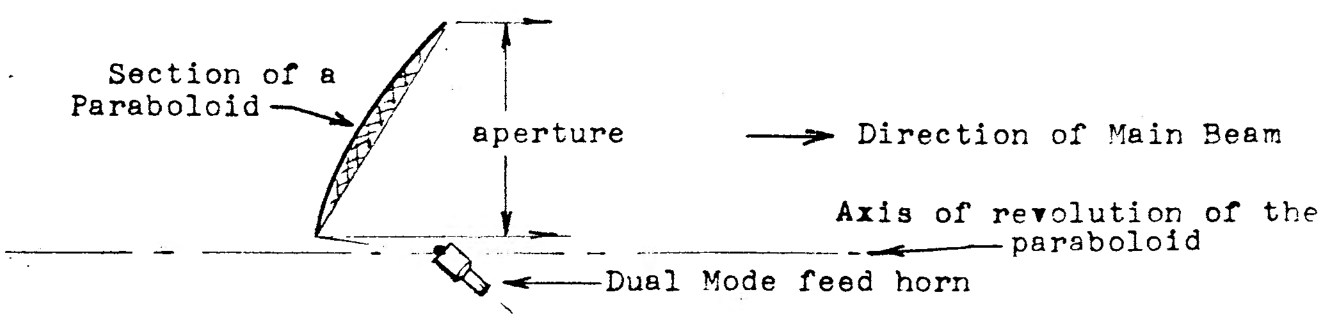
The parabolic reflector antenna design presented in Technical Report # 5 was a standard front fed 'dish' type antenna. This widely used antenna type provides high gain with good efficiency in the UHF and microwave frequencies. There are however several disadvantages to this standard design. (a) The prime focus feed is directly in front of and in the center of the electrical aperture. (b) The feed must be supported by struts which are also in front of the aperture. (c) With the large reflectors required for EME service, the feed is difficult to reach for adjustment while in service. The latter is a primary disadvantage not only because it is physically difficult to reach the feed but for EME service both the receiver low noise preamp and the last stage(s) of the power amplifier should be located at the feed to minimize feedline losses which can be very significant at 1296 mc/s. These equipments when mounted at the feed can increase the aperture blockage and scattering of energy from the center of the aperture where the energy density is maximum.

The implication of the above is that initial tune-up and subsequent maintenance and adjustments of the feed, preamp or PA to optimize the system in service will place the person doing the work also in the area of maximum energy. This results in exposure to high r-f fields on transmit and further blockage to the aperture area for either transmit or receive. In short, 'hot' adjustments of the feed will be hazardous and difficult to perform properly. The implication of (a) and (b) are decreased antenna gain by blockage and higher antenna noise by scattering.

While all these effects are relatively small (the order of 1 db typically) in terms of the antenna gain they are definitely detriments to high performance required in EME service. It is the express purpose of this report to acquaint the EME enthusiast with methods and techniques to obtain maximum performance with parabolic reflector antennas at UHF. To this end, the off-set fed parabolic reflector antenna is presented as an improvement over the front-fed parabolic reflector antenna.

The Off-Set Fed Parabolic Reflector Antenna

All of the above shortcomings of the front fed reflector antenna can be overcome by changing the geometry of the parabolic reflector to an off-set fed reflector as shown below in side view.



The term off-set refers to the section of the paraboloid off-set from the axis of the paraboloid. The feed horn aperture (phase center) remains at the focal point of the paraboloid but the feed is aimed so as to illuminate the off-set section of the paraboloi In this report a design directly related to the high efficiency dual-m feed horn is chosen as a desirable and compact arrangement. The geometric considerations presented later are specifically for this particular design.

With the off-set geometry the feed is at once out of the antenna aperture, the feed supports need not be in the antenna apertur at all, the feed is closer to the ground and most importantly, the feed may be loaded with equipments which may be adjusted without electrical intervention of the person doing the adjustments. The importance of being able to get to the feed and associated equipments for initial adjustments of focal position, impedance matching and optimizing preamp noise performance as well as maintenance cannot be stressed enough.

A more subtle advantage of the off-set feed is that since the feed is outside of the electrical aperture there will be no interaction between feed and reflector as there is with a front fed reflector. design and all of the initial optimizing adjustments will be more straightforward.

Elimination of reflections between feed and reflector is especially important when using circular polarization. In the front fed design circularly polarized energy transmitted in one sense of rotation is reflected back to the feed in the opposite sense. This means that the transmit-receive port isolation is limited to $G\lambda / 4\pi f$, where f is the focal length, G is the feed absolute gain (typically $G \cong 10$ for the dual-mode feed) and λ is the free space wavelength. A 20 ft diameter front fed reflector with f/D = 0.6 will have an isolation of about 26 db at 1296 mc/s. For 500 watts at the feed transmit port there will result in 1.25 watts at the receive port! In the off-set design the T-R isolation can be nearly perfect with any polarization.

It is characteristic of the off-set parabolic reflector assymetric geometry to radiate cross polarized energy with linear polarization**. The cross polarized radiation increases with shorter focal length and larger off-set angle. Cross polarized radiation is found not on axis of the main beam but in the 45° planes close to the main beam. This radiation is small but is completely lost energy in terms of antenna gain.

Another characteristic of the off-set reflector antenna is that with circularly polarized feed energy there results no cross polarized radiation but instead a slight misalinement of the main beam.

* Radiation Lab. Series, MIT, Vol 12, page 440.

** T. S. Chu and R. H. Turrin, "Depolarization Properties of Off-set Reflector Antennas", IEEE, PGAP, Vol AP-21, #3, May 1973, pp.339-345.

The main beam misalinement is in the horizontal (i.e. transverse) plane and is to the left of center for right circular polarization for a transmitted wave receding from the antenna. The error in pointing of the main beam from left to right circular polarization is only a fraction of the beamwidth which results in a gain difference from left to right C.P. of only a fraction of a decibel. For example a 20 foot (3 meter) aperture off-set reflector antenna with off-set angle of 45° at 1296 mc/s (the design detailed in this report), the pointing angle will change $3/4^{\circ}$ from right to left CP while the main beamwidth is of the order 4°. The resulting gain difference is about 0.1 db.

It is desirable to employ circular polarization for the EME path to eliminate Faraday rotation fading through the ionosphere. The off-set reflector antenna is suited to circularly polarized application. As mentioned previously the off-set feed virtually eliminates the coupling between transmit and receive ports via reflections from the reflector surface back into the feed. It now is highly desirable to consider the circularly polarized feed method suggested in Tech. Reports #1 and #2 which makes use of the C.P. dual mode feed presented in Report #9. This scheme takes advantage of the isolation between opposite sense circularly polarized ports to eliminate the need for a T-R relay or switch. With this method if all EME stations transmit one sense C.P. and receive in the opposite sense then all stations will be compatible with each other and with their own echoes. The obvious advantages of this scheme are elimination of Faraday fading, no polarization tracking or searching, no T-R switch required in the antenna feed, complete polarization compatibility and elimination of cross polarized radiation which results in maximizing gain.

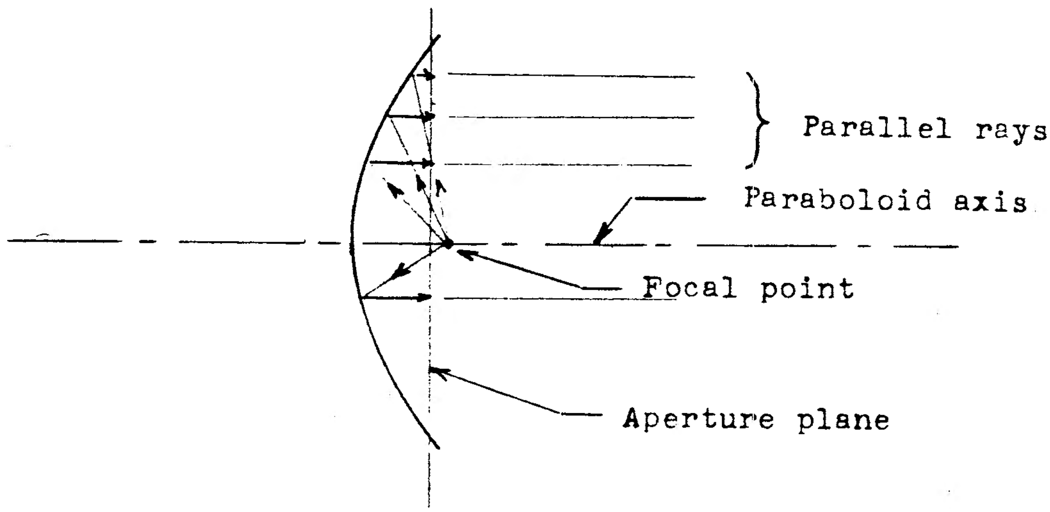
Another advantage of the off-set geometry is for multi-band operation where the feed package may be easily changed by virtue of its accessibility and non critical space requirement. That is the feed and equipments may be packaged in almost any size and shape since there is no blockage problem. It is conceivable to mount two complete feed packages on swinging booms to facilitate changing bands.

For strictly EME service with good foreground clearance in the direction of the Moon orbit, the lower edge of the reflector may be mounted near to the ground and may also be the location of the elevation axis. In this arrangement the feed will be easily accessible even for moderate elevation angles. For a given aperture size and with an off-set angle of 45° the feed will be 16% closer to the reflector in the off-set design compared with the front fed design.

If there is any disadvantage to the off-set reflector antenna design it is the different and somewhat awkward geometry. The remainder of this report will present geometric details and suggestions for construction of a specific off-set parabolic reflector antenna design.

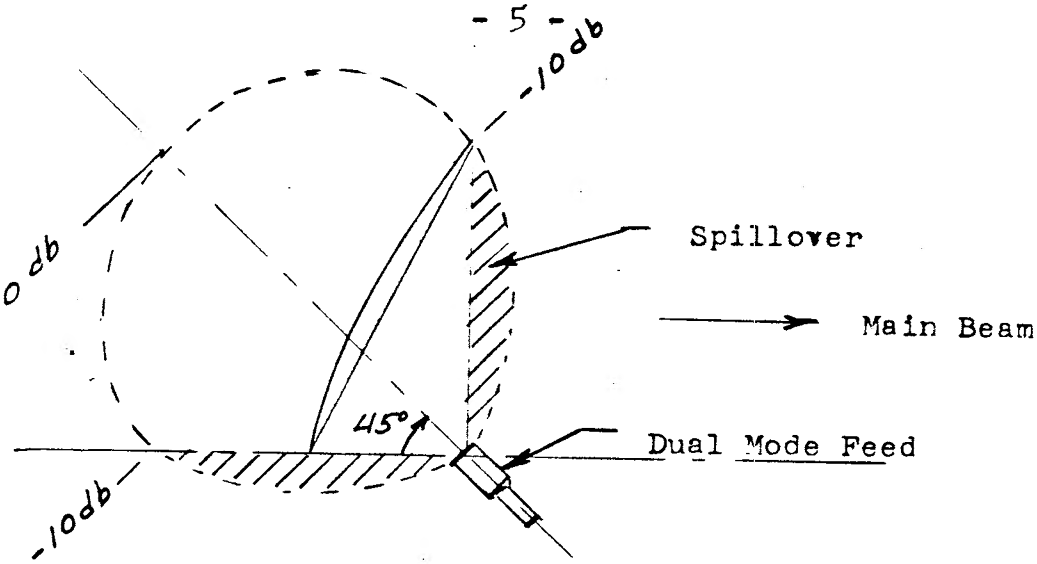
Off-Set Geometry

The geometry of the off-set reflector antenna may be developed from basic properties of a parabolic reflector. One property is that all rays of energy that originate at the focal point of a paraboloid will be reflected in a direction parallel with the axis of the paraboloid as shown below.



It is also a basic property of a parabolic reflector that the total length of each reflected ray from the focal point to the aperture plane is a constant length. This latter property means that energy at a fixed frequency originating at the focal point will be distributed over the aperture plane with uniform (constant) phase. These properties cause the beam forming characteristic of a parabolic reflector antenna much the same as a flashlight produces a beam of light when the bulb filament is located at the focal point of the small mirrored parabolic reflector in the flashlight.

Since all rays emanating from the focal point behave in the same way, we may choose to direct energy from the focal point to any region of the paraboloid which will then form a beam. In the design described in this report we choose a region just off the paraboloidal axis so that the feed antenna is outside of the region (aperture area) of the reflected rays. The term off-set therefore designates that the reflector surface region used is off-set from the paraboloidal axis but the feed horn antenna is still located at the focal point. The feed horn axis is however tilted to illuminate the chosen area of the reflector surface and the center of the feed horn aperture (phase center) is located at the focal point of the paraboloid. A cross sectional drawing of this geometry is shown below for the particular case of the dual mode feed. The dual mode feed is chosen not only because of its high illumination efficiency as pointed out in Report #5 but because it will also result in the most compact form of the off-set antenna design.



The constraint on feed illumination is the same as with the front fed case, that is for maximum gain the -10 db contour of the feed radiation pattern should fall at the edge of the reflector surface. The spillover will be the same in both cases and the gain between the two designs in terms of aperture efficiency will be the same. The difference in effective gain between the two cases is due to blockage of feed and struts which will be 0.5 db or more.

Since the feed radiation characteristic of the dual mode horn are circularly symmetric, the -10 db radiation surface contour may be represented by a cone whose apex is located at the focal point of the paraboloid and whose half cone angle is 45°. The geometry of the off-set fed parabolic antenna may therefore be simply described as the intersection of a cone and a paraboloid. Figure 1. shows various useful views of this geometry with simple formulae to calculate all necessary dimensions and angles. The views shown by the drawing are specifically for the dual mode feed with off-set angle of 45°.

Several useful properties of this geometry which may be readily proven are: (1) the projected area of illumination of the reflector in the direction of the main beam (parallel with axis of paraboloid) is a circular disc (the aperture area). (2) The edge or rim of the illuminated area on the reflector is elliptic and lies in a tilted plane. These characteristics make it easier to visualize the physical construction. Be assured therefore that even though the off-set geometry is awkward its physical properties are described by simple geometric figures.

In the aperture view, to the right in Figure 1, the dotted radial lines represent lines of the same parabolic shape. If a trussed rib type construction is employed these trussed ribs can all be made on the same template but of different lengths. All the ribs will converge at the vertex V at the bottom of the aperture where a support hub may be used as the main structural mount.

Construction Notes

The following notes are included merely as a suggestion guide for building an off-set reflector antenna including mount, strictly for EME use.

Since an EME antenna will be large, the basic considerations in construction will be selection of a suitable site and keeping the structure low to the ground to minimize structural wind loading problems. The site selection should allow minimum obstruction to the radio beam over as large a portion of the Moon orbit as possible.

Figure 2 is a sketch of a complete off-set fed reflector antenna and mount. The mount consists of a well anchored vertical post which serves as the azimuth pivot. It is located at the center of a circular track near ground level upon which the mount will turn on wheels.

The mount frame should be triangular with running wheels near the corners. This provides a simple three point support which will not teeter. The circular track may be of poured concrete with footing suitable to the local climate and just wide enough to support the total antenna load (estimate 1000 pounds for a 20 ft reflector). The wheels can be solid rubber type found in hardware stores as replacements for garden equipment and need not be very large in diameter. Several wheels may be stacked at each cornerof the frame for extra load bearing surface. Pneumatic type wheels might be satisfactory if inflated to high pressure to prevent tilting of the mount frame with unbalanced loads.

The central pivot should also provide for a thrust bearing to hold the frame down securely onto the track. A track diameter of no less than 15 feet is recommended for this size antenna (20 ft aperture The central pivot should be set plumb in concrete and the circular track leveled carefully. Since the antenna structure will turn slowly around the pivot, the actual bearing may be very crude.

Azimuth drive may be through friction drive directly to a support wheel. If the drive motor is coupled through a worm gearbox, braking will be automatic. Azimuth angular readout may also be taken conveniently from an idler wheel which runs on the track. By sizing the idler wheel diameter it may be used to drive a synchro directly for fine readout and through a suitable gearbox for coarse readout. A bench mark calibration of true North (or any other reference) will permit rapid check and realinement of the readout should it slip or accumulate error. A readout accuracy of 0.5 to 1.0 degree should be achieved.

Once the azimuth pivot, track and frame have been completed, construction of the reflector frame with elevation pivots can be started. The elevation pivots can also be relatively crude since rotation will always be slow.

The reflector frame should be constructed in the "stow" position, that is with the radio beam pointed straight up. This frame as well as the azimuth triangular frame may be fabricated of relatively heavy material to provide rigidity and strength for the actual reflector and feed support. Details of the reflector frame are shown approximately by Figure 2 with additional stiffaners and supports added where necessary. The depth of the frame from elevation pivot to reflector vertex need not be more than 3 feet for this size antenn a.

Since this design does not use counter weights to balance the elevation forces, the structure is inherently unbalanced except at one elevation angle. For this reason the elevation drive suggested is a system of dual lead screws or hydraulic jacks one adjacent to each pivot bearing as shown by the sketch. Also, because the antenna is near the ground it will be difficult to track the Moon to rise and set times due to obstructions in the radio beam. The range of elevation movement may therefore be limited for your site thus minimizing the requirements of the drive system. Auxiliary drives may be required to "stow" the antenna.

Construction of the reflector should begin with fabrication of an accurate reverse template and pivot assembly which will be the guide for placement of the trussed ribs and as final surface alinement tool. The template pivot should be secured to the reflector frame at exactly the vertex of the paraboloid. Actual construction of the trussed ribs and supports is left to the individuals imagination. Most of the support will be near the vertex and towards the center of the reflector. The rim need not provide much support in this design. Reflector construction using the materials and techniques described in an article by VK3ATN in Ham Radio Magazine, p 12, May '74. is recommended.

The feed support tower is added last and may be partially secured to the reflector by a few thin steel wires for added rigidity.

Surface material for the reflector should be chosen according to the highest frequency of operation. As a reminder, the surface material hole size should not exceed 0.1 wavelength at the highest frequency. The material need not be bonded together electrically at overlapping joints provided no joints are closer together than a wavelength at the lowest operating frequency and the overlaps are at least a quarter wavelength at the lowest operating frequency. Deviation of the surface from a true paraboloid should not exceed 0.05 wavelength at the highest frequency especially towards the center area of the reflector where the energy density is highest. If the rib construction is not too accurate, trimming up the surface is highly recommended.

Refer to Figure 1 for more details of the geometry and placement of the feed. The circular rings around the vertex shown in Figure 1 are added on top of the ribs and are the actual surface material support. These circular arcs may be made of lighter material an placed about a foot apart.

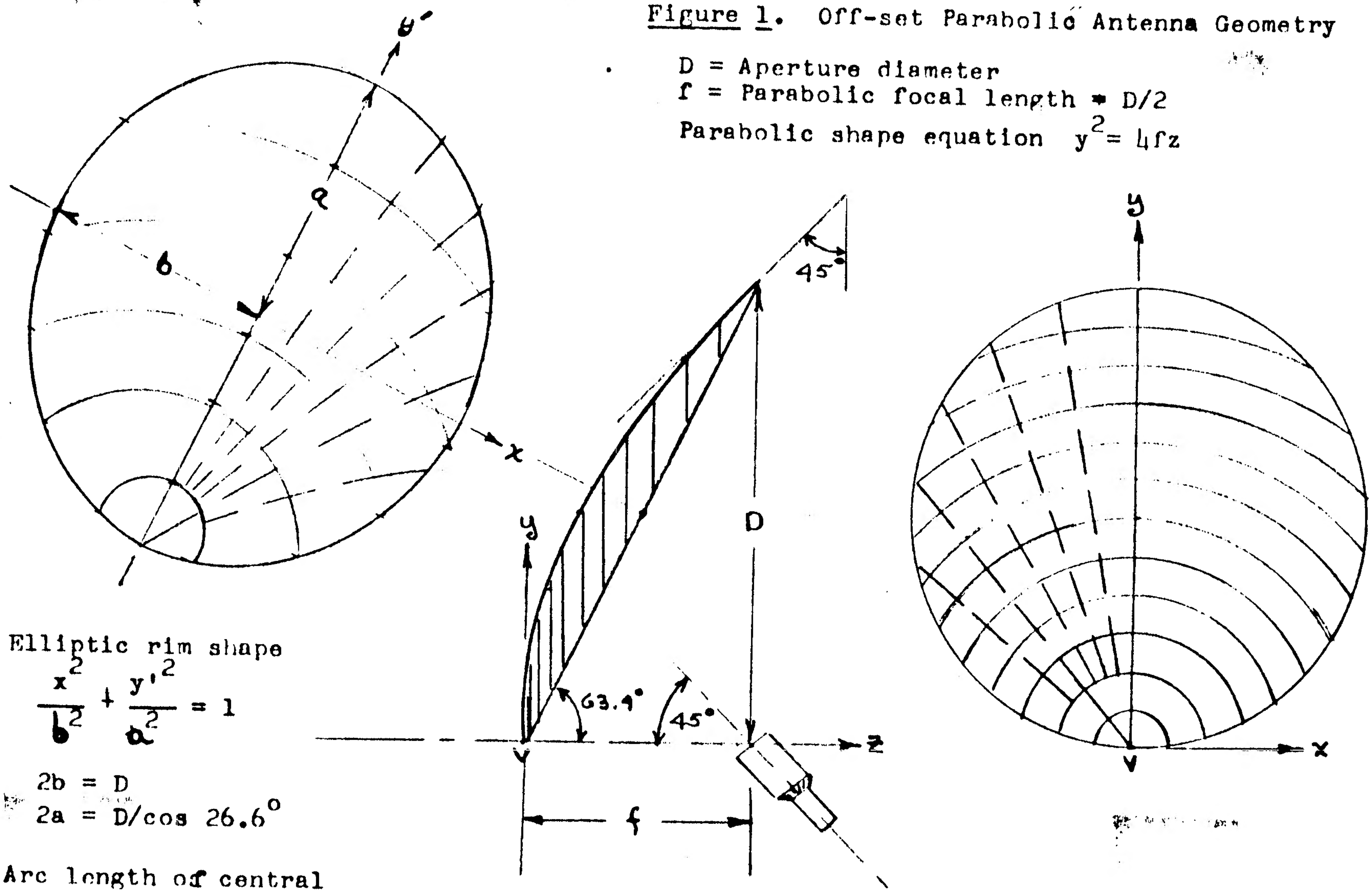
In the stow position the reflector frame should come to rest and be secured to the azimuth frame. This position provides the least wind loading. Provisions should be made to anchor the azimuth frame in severe weather.

A project of this magnitude should be given careful consideration especially with regard to expense, construction time, site location and family-neighborhood complications. In fact if your site is not acceptable it would probably be advisable to join forces with a nearby EME enthusiast who has an acceptable site. Remote control operation might be a solution for joint operation.

Since a reflector antenna may be used over a wide frequency range by changing feeds, it would be highly desirable to make the reflector surface as accurate as possible in anticipation of use above 432 mc/s, possibly 1296, 2400 and 4000 mc/s the satellite TV band!

Figure 1. Off-set Parabolic Antenna Geometry

D = Aperture diameter
f = Parabolic focal length = D/2
Parabolic shape equation $y^2 = 4fz$



Elliptic rim shape

$$\frac{x^2}{b^2} + \frac{y'^2}{a^2} = 1$$

$2b = D$
$2a = D/\cos 26.6^{\circ}$

Arc length of central parabolic section

$S = 2.2956\ f$

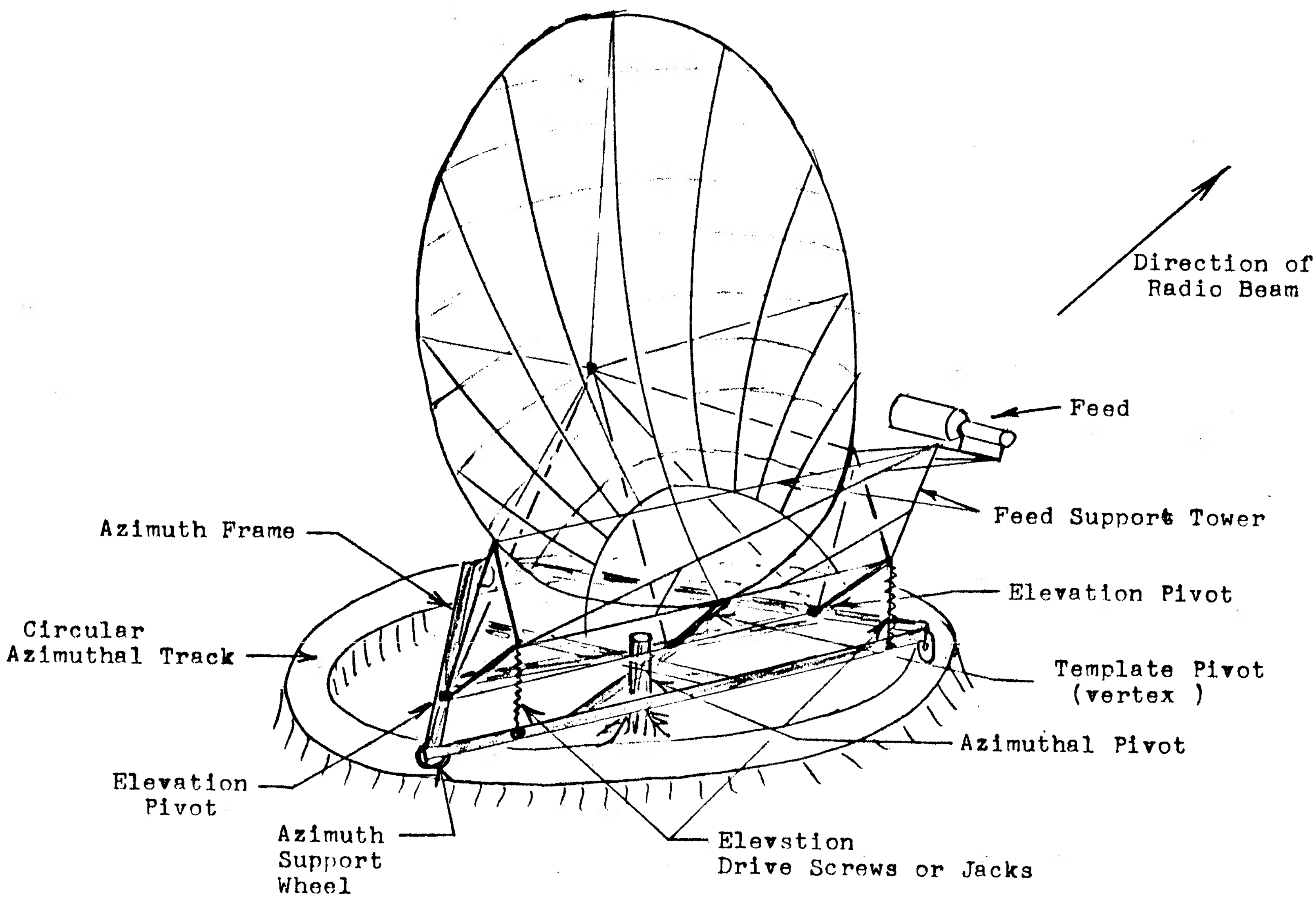


Figure 2. A sketch of an off-set fed parabolic reflector antenna for Moonbounce application.